Experimental test of spin-triplet superconductivity in Sr_2RuO_4

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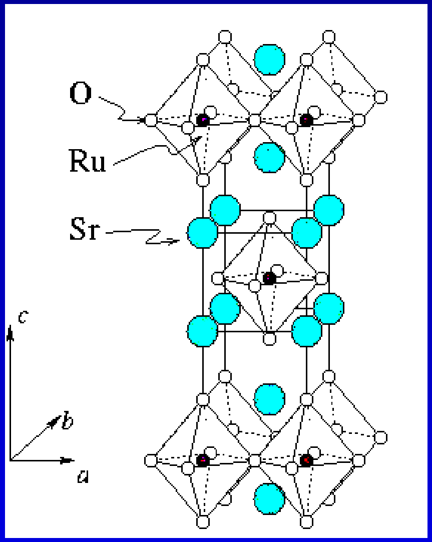
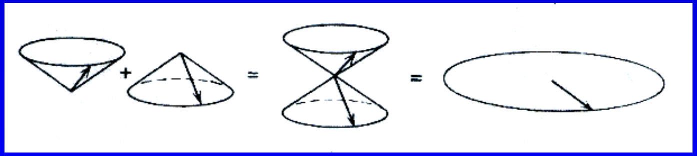
Sr_2RuO_4: A leading candidate for Spin-triplet superconductor!

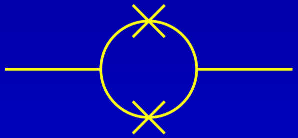


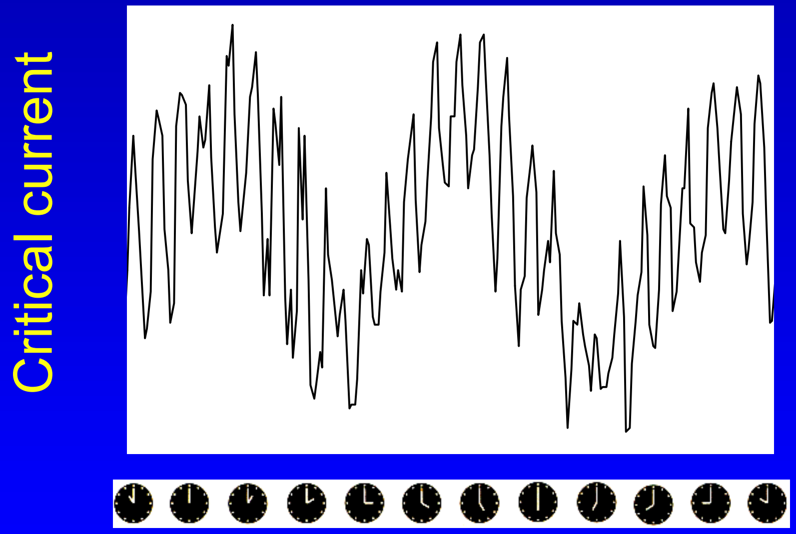


$$(|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle)(k_x \pm ik_y)$$

$S = 1$, $S_z = 0$

Our SQUID-based phase-sensitive measurements show that Sr_2RuO_4 is indeed a spin-triplet superconductor.





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Almost all superconducting materials studied thus far, including high-T_c cuprates, are even-parity, spin-singlet (*s*- or *d*-wave) superconductors. Theoretical studies of systems where spin-triplet pairing may be realized, ranging from neutron stars to superconductor-ferromagnet nanostructures, have revealed exotic properties of these unconventional superconductors, raising the possibility of using them for novel applications. Experimentally, superfluid ^{3}He has long been considered the only established example of odd-parity, spin-triplet pairing. Sr_2RuO_4, the only layered perovskite that becomes superconducting without the presence of Cu, has in recent years emerged as a leading candidate for odd-parity superconductors.

Prior to our phase-sensitive experiment, the constant spin susceptibility observed in the nuclear magnetic resonance Knight shift measurements were considered the strongest evidence for spin-triplet superconductivity in Sr_2RuO_4. However, reasons unrelated to pairing symmetry are also known to lead to constant spin susceptibility. For example, the Knight shift of vanadium, an *s*-wave superconductor, is unchanged across T_c. A phase-sensitive experiment provides the most stringent test on the pairing symmetry of a superconductor, as shown in the high-T_c work.

We have prepared $Au_{0.5}In_{0.5}$-Sr_2RuO_4 superconducting quantum interference devices (SQUIDs) and showed that the phase of the order parameter in Sr_2RuO_4 changes by π under inversion. This experiment, which has taken more than 7 years to complete, has provided the first *definitive* experimental proof that Sr_2RuO_4 is an odd-parity superconductor, and likely the last push for Sr_2RuO_4 to find its way into textbooks.

Right: the crystal structure of Sr_2RuO_4, a schematic of a spin triplet of two 1/2 spins, the form of the superconducting order parameter (for a spin-triplet, chiral "p-wave" superconductor) that includes both the spin and the orbital parts of the order parameter; Left: The symbol of a SQUID, the quantum interference pattern of one $Au_{0.5}In_{0.5}$-Sr_2RuO_4 sample (critical current vs magnetic field).

Because of quantum mechanics, the total wave function of a Cooper pair of two electrons, which is the superconducting order parameter, has to be odd (Fermi statistics). Since the wave function of the spin part for the triplet is even, the spatial part must be odd. Our SQUID-based phase-sensitive measurements probes the odd-parity of the spatial wave function using a SQUID consisting two oppositely faced Josephson junctions between a conventional s-wave superconductor $Au_{0.5}In_{0.5}$ and Sr_2RuO_4. The phase, which is represented schematically here by little clocks, is tuned by magnetic field. From the characteristics of the interference pattern of these SQUID show that Sr_2RuO_4 is indeed an odd-parity, spin-triplet superconductor.

Training of future scientists in a multi-discipline, international environment: List of participants and collaborators at various stages of this research

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